Final Report

Statistical Evaluation of the Vegetation Inventory and Monitoring Program at Shenandoah National Park

Submitted by:

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EXECUTIVE SUMMARY

Effective programs designed to monitor changes in natural resources set objectives that can be assessed quantitatively, implement a sound sampling design, and evaluate the program to determine if the sampling design and methods meet specified objectives. In turn, the evaluation of the program should be used to modify objectives or methods, if necessary, to ensure that results are valid and are useful to scientists, managers, and administrators. This report presents findings of an evaluation the Long-Term Ecological Monitoring System (LTEMS) at Shenandoah National Park (SNP) to meet inventory and monitoring objectives. The objectives were developed during a workshop held at SNP on March 21, 2000 (Mahan 2000).

I used data collected as part of the LTEMS program at SNP from 1987 - 2000, to estimate basal area of trees (m^2/ha), stem density of shrubs and saplings (stems/ha), and stem density of seedlings (vegetation <1 m tall). Also, I used data collected at the Big Meadows site to estimate changes in shrub coverage pre- and post-treatment of mowing. The coefficient of variation (CV = standard error/mean x 100%) was used as a measure of the precision of an estimate. A CV $\leq$ 10% is generally considered necessary for research, a CV $\leq$ 25% is recommended for management, and a CV $\cong$ 50% is usually sufficient for pilot studies. The species for which basal area and stem density were calculated were determined in consultation with SNP staff. All forest cover types were sampled $\geq$2 times during 1987 - 2000, although they were not sampled during the same year such that park-wide estimates for any given year could be calculated. These data provided variances that were incorporated into a power analysis to assess whether the current LTEMS and Big Meadow sampling designs could meet stated inventory and monitoring objectives.

The objectives evaluated were the following:

1. Data collected for the LTEMS program should ensure a 90% probability of detecting a 50% change in the density of any one species of tree within any one forest cover type over a 5-year period ($\alpha = 0.20$). I assessed the ability of current sampling efforts to meet this objective by calculating power curves for tree basal area, shrub and sapling stem density, and seedling stem density.
2. Data collected for the LTEMS program should ensure an 80% probability of detecting a 20% change in the coverage of a particular exotic species parkwide over a 5-year period ($\alpha = 0.20$). I assessed the ability of the current LTEMS program at SNP to meet this objective using the power curves calculated above for changes in seedling and sapling stem density of tree-of-heaven (*Ailanthus altissima*).
3. Data collected for the LTEMS program should ensure an 80% probability of detecting a 20% change parkwide in species affected by disease or insects over a 5-year period ($\alpha = 0.20$). I assessed the ability of the current LTEMS program at SNP to meet this objective using the power curves calculated above for changes in stem density of flowering dogwood (*Cornus florida*) and basal area of all oak species.
4. Monitoring of shrub coverage at Big Meadow should ensure a 95% probability of detecting a 40% reduction in shrub coverage over a 5-year period ($\alpha = 0.15$). I used program TRENDS to estimate the statistical power to detect these changes.

For basal area, most CVs were <40% for species in forest cover types where they were dominant (e.g., northern red oak [*Quercus rubra*] in northern red oak cover types). Declines in oaks because of mortality due to gypsy moth infestations and the decline of Virginia pine (*Pinus virginiana*) and pitch pine (*Pinus rigida*) were evident from the changes in estimated basal area between sampling periods. The results of the power analysis suggested that changes of 5 - 6 m^2/ha could be detected with $\geq$90% power.

For stem density of shrubs and saplings, most CVs were >50% (Range 31 - 1,169%). The power analysis suggested that stem density changes of $\geq$2,000 stems/ha had >90% probability of being detected. Thus, current sample sizes are inadequate to detect important changes in stem density of shrubs and saplings. Most stem densities during both sampling periods were <1,000 stems/ha.

Stem density of seedlings was extremely variable, and the power analysis suggested that only extremely large changes in stem density (>50,000 stems/ha) could be detected under the current sampling effort. Moreover, large enough sample sizes likely cannot be obtained to meet stated objectives because of the inherent variability of these data.

The current sampling design for Big Meadow should provide estimates of shrub coverage, and estimates of changes in shrub coverage, with CVs < 20%. Although estimates of coverage for individual shrub species were not precise, biologically important changes in overall shrub coverage should be detected under the current sampling design.

Below I describe the most important recommended changes to the LTEMS program at SNP so that monitoring objectives can be met. Additional recommendations are detailed in the report.

1. Sample sizes need to be increased such that all strata contain >1 plot. Sample sizes, for the current sampling design, need to be at least doubled to meet objectives for detecting changes in stem density of shrubs and saplings.
2. A sampling design needs to be implemented that will permit park-wide estimates of vegetation parameters for a given point in time. Presently, changes in basal area or stem density can be estimated within each forest cover type, but cannot be estimated across all cover types for the same time period because each forest cover type is visited in a different year.
3. Trees within plots should continue to be permanently marked with unique identifiers to reduce misidentification and data collection errors.
4. An electronic field-based data entry system should be fully implemented to speed data collection, reduce data entry errors, and eliminate transcription errors that may occur with a paper system.
5. Review the purpose and need to collect seedling stem densities. It is unlikely that it will be possible to obtain adequate sample sizes to detect biologically important changes in seedling density or abundance.
6. Investigate the requirements to monitor the spatial distribution of forest cover types before implementing changes to the sampling design. Traditional stratified sampling designs cannot incorporate changes in the distribution of cover types over time.

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INTRODUCTION

Any program to monitor status and trends in natural resources should (1) set quantifiable objectives, (2) define the target population and decide upon an enumeration method (e.g., counts, index, etc.), (3) develop a sampling design, and (4) estimate statistical power to detect a trend given the chosen sampling design and expected variances (Thompson et al. 1998). In fact, this four-step process can be used iteratively to develop a monitoring program that meets objectives in the most efficient and cost-effective manner.

Shenandoah National Park (SNP) established a long-term monitoring program (Long-Term Ecological Monitoring System [LTEMS]) as the basis for the park's natural resource management program. The overall goals of the LTEMS program are to (Smith and Torbert 1990, SHEN 1991): (1) obtain and maintain a scientifically-based understanding of the type, abundance, and distribution of natural resources, (2) monitor resource condition and changes through time, and (3) monitor natural processes and anthropogenic influences that maintain or affect ecosystem health.

An initial step in evaluating the monitoring program at SNP was to choose several examples within the monitoring program and evaluate the statistical power of these data to detect specific trends (Gibbs 1998). The outcome of this work suggested that a more formal evaluation of the program was needed to ensure that stated objectives were being met. Consequently, a 1-day workshop was convened to develop specific, appropriate, measurable, and statistically-defined objectives for Shenandoah National Park's Vegetation Inventory and Monitoring Program (Mahan 2000).

A workshop was held at SNP headquarters in Luray, Virginia on March 21, 2000 with 14 participants from ten university, government and non-government organizations. The workshop participants were asked to assist resource managers at SNP in determining what to inventory and monitor and what sort of trends and status they should be able to detect. The participants in this workshop developed specific objectives for the monitoring program in terms of detecting trends and status of the vegetation in the areas of general forest trends (e.g., tree species composition, tree growth rates, etc.), forest health (e.g., trends in hemlock woolly adelgid infestation), and special and unique ecosystems and species (e.g., trends in abundance of endangered plant species).

At the time of this report, SNP had more than a decade of vegetation data collected via the LTEMS program. By taking specific objectives developed in the March Workshop at SNP, and using existing data to obtain measures of statistical variability and magnitude, the ability to estimate parameters with specified precision or detect changes was evaluated. In this report I statistically evaluated specific objectives developed in the March 2000 workshop at SNP and make recommendations regarding the LTEMS program. Part I of this report contains estimates of basal area and stem density for trees, shrubs and saplings, and seedlings. Part II presents estimates of statistical power to detect the changes specified in established objectives.

PART I - STATISTICAL SUMMARY OF DATA, 1987 – 2000

INTRODUCTION

Estimates of variances and effect sizes (e.g., changes in basal area) are required before statistical power of some parameter can be estimated. Therefore, the first part of this report presents estimates of basal area and stem density of selected species or groups of species throughout the park, and shrub coverage for selected species at the Big Meadows area. The information obtained from this section was then used in Part II to estimate statistical power of the current sampling design to detect specified changes in vegetation characteristics in SNP.

METHODS

Data analyzed in this report were provided by SNP staff from two sources: (1) the LTEMS database for the years 1987 - 2000 at 104 sampling sites, and (2) the 1998-2000 data collected at the Big Meadows area.

LTEMS data – Ninety-one of the 104 LTEMS sites were randomly selected for a stratified random sampling design developed in 1985, and the additional 13 sites were added as part of subsequent research projects (W. Cass, SNP, personal communication). The strata were eight forest cover types (cove hardwoods, pitch pine, Virginia pine, eastern hemlock, chestnut oak, black locust, northern red oak, and yellow poplar), three elevation ranges (low 381 - 533 m; mid 686 - 838 m; high 991 - 1143 m), and two aspect ranges (moist 350 - 100 degrees azimuth; dry 170 - 280 degrees azimuth) (W. Cass, SNP, personal communication). In addition, whenever possible sample plots were located in each of the three park districts (north, central, and south). Table 1 lists the characteristics associated with each sampling site.

Table 1. Characteristics of 104 sampling sites in Shenandoah National Park, 1987 - 2000, used to evaluate the vegetation monitoring program, which included the forest cover type, aspect (moist 316 - 135 degrees; dry 136 - 315 degrees), and elevation (low 381 - 609 m, mid 610 - 914 m, high 915 - 1143 m).

Sampling site	Forest cover type	Aspect	Elevation
1L11	Cove Hardwoods	Dry	High
2L11	Cove Hardwoods	Dry	High
3L10	Cove Hardwoods	Dry	High
1L11	Cove Hardwoods	Dry	Low
1L11	Cove Hardwoods	Dry	Low
3L11	Cove Hardwoods	Dry	Low
1L11	Cove Hardwoods	Dry	Mid
2L11	Cove Hardwoods	Dry	Mid
3L11	Cove Hardwoods	Dry	Mid
2L11	Cove Hardwoods	Mois	High
3L10	Cove Hardwoods	Mois	High
1L11	Cove Hardwoods	Mois	Low
2L11	Cove Hardwoods	Mois	Low
3L11	Cove Hardwoods	Mois	Low
1L10	Cove Hardwoods	Mois	Mid
2L11	Cove Hardwoods	Mois	Mid
3L11	Cove Hardwoods	Mois	Mid
2L12	Pitch Pine	Dry	High
2L12	Pitch Pine	Dry	High
1L12	Pitch Pine	Dry	Low
2L12	Pitch Pine	Dry	Low
3L12	Pitch Pine	Dry	Low
1L12	Pitch Pine	Dry	Mid

Table 1. Continued.

Sampling site	Forest cover type	Aspect	Elevation
2L13	Pitch Pine	Dry	Mid
3L11	Pitch Pine	Dry	Mid
1L12	Pitch Pine	Mois	Low
3L12	Pitch Pine	Mois	Low
3L12	Pitch Pine	Mois	Mid
1L12	Virginia Pine	Dry	Low
3L12	Virginia Pine	Dry	Low
1L12	Virginia Pine	Dry	Mid
1L12	Virginia Pine	Mois	Mid
2L13	Virginia Pine	Mois	Mid
2L12	Eastern Hemlock	Dry	Low
3L11	Eastern Hemlock	Dry	Low
2L13	Eastern Hemlock	Dry	Mid
2L12	Eastern Hemlock	Mois	High
1L12	Eastern Hemlock	Mois	Low
2L12	Eastern Hemlock	Mois	Mid
2L10	Chestnut Oak	Dry	High
2L30	Chestnut Oak	Dry	High
1L31	Chestnut Oak	Dry	Low
2L10	Chestnut Oak	Dry	Low
1L31	Chestnut Oak	Dry	Mid
2L31	Chestnut Oak	Dry	Mid
2L10	Chestnut Oak	Mois	High
2L13	Chestnut Oak	Mois	High

Table 1. Continued.

Sampling site	Forest cover type	Aspect	Elevation
1L10	Chestnut Oak	Mois	Low
1L30	Chestnut Oak	Mois	Low
2L10	Chestnut Oak	Mois	Low
2L31	Chestnut Oak	Mois	Low
3L10	Chestnut Oak	Mois	Low
3L10	Chestnut Oak	Mois	Low
1L31	Chestnut Oak	Mois	Mid
2L10	Chestnut Oak	Mois	Mid
2L31	Chestnut Oak	Mois	Mid
3L10	Chestnut Oak	Mois	Mid
2L11	Black Locust	Dry	High
1L11	Black Locust	Dry	Low
1L11	Black Locust	Dry	Mid
2L11	Black Locust	Dry	Mid
3L11	Black Locust	Dry	Mid
3L11	Black Locust	Dry	Mid
2L11	Black Locust	Mois	High
1L11	Black Locust	Mois	Low
2L11	Black Locust	Mois	Low
3L11	Black Locust	Mois	Low
1L11	Black Locust	Mois	Mid
2L11	Black Locust	Mois	Mid
3L11	Black Locust	Mois	Mid
1L10	Northern Red Oak	Dry	High

Table 1. Continued.

Sampling site	Forest cover type	Aspect	Elevation
1L10	Northern Red Oak	Dry	High
2L10	Northern Red Oak	Dry	High
2L31	Northern Red Oak	Dry	High
3L10	Northern Red Oak	Dry	High
1L10	Northern Red Oak	Dry	Low
2L10	Northern Red Oak	Dry	Low
3L10	Northern Red Oak	Dry	Low
1L10	Northern Red Oak	Dry	Mid
1L30	Northern Red Oak	Dry	Mid
2L10	Northern Red Oak	Dry	Mid
3L10	Northern Red Oak	Dry	Mid
1L10	Northern Red Oak	Mois	High
2L31	Northern Red Oak	Mois	High
3L10	Northern Red Oak	Mois	High
1L10	Northern Red Oak	Mois	Low
1L30	Northern Red Oak	Mois	Mid
1L30	Northern Red Oak	Mois	Mid
2L10	Northern Red Oak	Mois	Mid
2L10	Northern Red Oak	Mois	Mid
3L10	Northern Red Oak	Mois	Mid
1L12	Yellow Poplar	Dry	Low
2L12	Yellow Poplar	Dry	Low
3L12	Yellow Poplar	Dry	Low
1L13	Yellow Poplar	Dry	Mid

Table 1. Continued.

Sampling site	Forest cover type	Aspect	Elevation
2L12	Yellow Poplar	Dry	Mid
3L12	Yellow Poplar	Dry	Mid
1L11	Yellow Poplar	Mois	Low
1L12	Yellow Poplar	Mois	Low
2L12	Yellow Poplar	Mois	Low
3L12	Yellow Poplar	Mois	Low
1L12	Yellow Poplar	Mois	Mid
2L12	Yellow Poplar	Mois	Mid
3L12	Yellow Poplar	Mois	Mid

[a]Virginia and pitch pine were combined into a single "Pine" cover type. See Table 2 for areal coverages for each elevation and aspect class.

The areal coverage of each stratum was provided by SNP using a Geographic Information System (GIS) in conjunction with a Digital Elevation Model (D. Hurlbert, NPS, personal communication). The original areal coverages used when the sampling design was created were not available. Therefore, because the areal coverages generated from the GIS were not exactly the same ones used as the sampling frame for selecting sample sites, some inconsistencies existed between strata and allocation of sample sites. For example, the GIS provided 27.2 ha in the high elevation yellow poplar stratum, and 46.2 ha of pine stratum at high elevation, but these strata were not defined in the original sampling design, probably because of their small area. I ignored these areas in my analysis because they represent <0.2% of the total area of the park. Aspects of 316 - 135 degrees azimuth were classified as moist and aspects of 136 - 315 degrees azimuth were classified as dry. The elevation ranges were 381 - 609 m (low), 610 - 914 m (mid), and 915 - 1143 m (high).

To estimate the population mean I used the following formula (Cochran 1977:90-91):

$$\hat{\bar{y}} = \frac{1}{N}\sum_{h=1}^{L} N_h \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h}$$

where N_h = number of hectares in stratum h, L = number of strata, y_{hi} = value for plot i in stratum h expressed on a per ha basis, n_h is the number of plots, and

$$N = \sum_{h=1}^{L} N_h .$$

To estimate the population variance of the mean I used the following formula (Cochran 1977:95)

$$\hat{v}\mathrm{ar}(\hat{\bar{y}}) = \frac{1}{N^2}\sum N_h (N_h - n_h)\frac{s_h^2}{n_h}$$

where n_h = number of plots in stratum h and s^2_h is defined as

$$s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h} (y_{hi} - \hat{\bar{y}}_h)^2.$$

Population totals and their associated variances were calculated as

$$\hat{Y} = N\hat{\bar{y}}$$
$$\hat{\text{v}}\text{ar}(\hat{Y}) = N^2 \text{ var}(\hat{\bar{y}}).$$

To calculate 95% confidence intervals for population means or totals when calculating a difference (e.g., difference in basal area between time 1 and time 2) I used the following formula

$$\hat{\tau} \pm t_{\alpha,df}\sqrt{\hat{\text{v}}\text{ar}(\hat{\tau})}$$

where $\hat{\tau}$ represents the estimate of either the population mean or total, the t-distribution is based on the upper $\alpha/2$ (90th) percentile, and the Satterthwaite degrees of freedom are calculated as

$$Satterthwaite\ df = \left(\sum_{h=1}^{L} a_h s_h^2\right)^2 \Bigg/ \left[\sum_{h=1}^{L} (a_h s_h^2)^2 / (n_h - 1)\right]$$

and

$$a_h = N_h(N_h - n_h)/n_h.$$

For estimates of population totals or means, in which the statistic of interest (e.g., basal area, stems/ha, etc.) was ≥ 0, I calculated a 95% confidence interval based on a log-normal distribution using the following formula

$$95\%\ CI = \left[\hat{\tau}/C, \hat{\tau}C\right]$$

where

$$C = \exp\left\{ t_{\alpha,df} \sqrt{\ln\left(1 + \frac{\hat{\mathrm{v}}\mathrm{ar}(\hat{\tau})}{\hat{\tau}^2} \right)} \right\}.$$

Several problems which arose in analyzing these data need to be explained so that the results can be interpreted correctly. First, all forest cover types were sampled $\geq$2 times during 1987-2000, but not all at the same time (Table 2). Consequently, although I could estimate changes in tree basal area and stem density for 2 time periods for each forest cover type, I could not make inferences across all forest cover types at any given point in time. Second, in eastern hemlock stands I was not able to apply the formulas for a random stratified design because most of the strata did not contain >1 sample plot, although most stands were sampled every year. Because of this problem, and that another sampling program was developed specifically to monitor hemlock stands in the park I did not analyze data from these stands. Third, some strata in black locust and northern red oak forest cover types did not contain >1 sample plot and thus the sampling variance for these strata were not incorporated into the variance estimate for the given forest cover type, or it was not possible to calculate any estimate of variance (Table 2). This means that the variance is underestimated for these strata. Fourth, the GIS could not separate the various pine stands so I analyzed pitch pine and Virginia pine as if they occurred in a single forest cover type (pine).

For the following tree species, or groups of species, I estimated total basal area (m^2) for each forest cover type at each sampling period, and the change in mean (m^2/ha) and total basal area (m^2) between sampling periods: (1) northern red oak (*Quercus rubra*), (2) red maple (*Acer rubra*), (3) all *Quercus* spp., (4) red oak species (*Q. coccinea, Q. falcata, Q. palustris, Q. rubra, Q. velutina*), (5) white oak species (*Q. alba, Q. bicolor, Q. prinoides, Q. prinus*), (6) yellow

Table 2. Summary of characteristics (area, number of plots, and years when sampled) of strata (vegetation type, elevation, and aspect) in Shenandoah National Park, 1987 – 2000.

					Period (years) sampled	
Vegetation type	**Elevation**	**Aspect**	**Area (ha)**	***n***	**First**	**Second**
Cove Hardwoods	High	Dry	823.6	3	1988-89	1993-94
		Moist	963.0	2	1988	1993-94
	Medium	Dry	2,716.8	3	1988-89	1993-94
		Moist	4,009.0	3	1988-89	1993-94
	Low	Dry	1,394.8	3	1988-89	1993-94
		Moist	1,702.4	3	1988-89	1993-94
Pine	High	Dry	34.5	2	1990-91	1999
		Moist	46.1	0		
	Medium	Dry	1,139.8	4	1990-91	1999
		Moist	518.3	3	1991	1999
	Low	Dry	1,799.0	5	1990-91	1999
		Moist	796.7	2	1991	1999
Chestnut Oak	High	Dry	1,062.2	2	1987-88	1992-94
		Moist	614.9	2	1988	1991-93
	Medium	Dry	11,324.2	2	1987	1992
		Moist	9,383.1	4	1987-88	1992-94
	Low	Dry	8,302.8	2	1987-88	1992-93
		Moist	7,286.8	6	1987-88	1992-94
Black Locust	High	Dry	381.8	1	1989	1994
		Moist	396.7	1	1989	1994
	Medium	Dry	830.4	4	1989	1994
		Moist	821.7	3	1989-90	1994
	Low	Dry	333.9	1	1989	1994
		Moist	433.6	3	1989	1994

Table 2. Continued.

Vegetation type	Elevation	Aspect	Area (ha)	*n*	Period (years) sampled	
					First	**Second**
Northern Red Oak	High	Dry	1,702.8	5	1988	1992-93
		Moist	1,874.4	3	1987-88	1992-93
	Medium	Dry	1,217.2	4	1987-88	1992-93
		Moist	1,528.8	5	1987-88	1993
	Low	Dry	558.9	3	1988	1992-94
		Moist	501.9	1	1988	1993
Yellow Poplar	High	Dry	9.1	0		
		Moist	18.1	0		
	Medium	Dry	2,024.6	3	1991	2000
		Moist	2,200.0	3	1991	2000
	Low	Dry	3,225.5	3	1991	2000
		Moist	4,598.6	4	1990-91	2000
Hemlock[a]	High	Dry	34.5	0		
		Moist	98.9	1	1990	2000
	Medium	Dry	77.2	0		
		Moist	139.5	1	1990	2000
	Low	Dry	86.0	2	1990	2000
		Moist	102.3	1	1990	2000
Total			76,576.1	98		

[a] Hemlock vegetation type was surveyed every year during 1990 - 2000, except 1991 and 1999.

poplar (*Liriodendron tulipifera*), (7) pitch pine (*Pinus rigida*) and Virginia pine (*Pinus virginiana*), (8) black locust (*Robinia pseudoacacia*), and (9) black birch (*Betula lenta*).

I estimated stem density (stems/ha) for shrubs and saplings (1 - 5 m tall) in each forest cover type, and changes in mean stem density for each of the following species and groups of species: (1) mountain laurel (*Kalmia latifolia*), (2) sassafrass (*Sassafras albidum*), (3) brambles (*Rubus* spp.), (4) spicebush (*Lindera benzoin*), (5) flowering dogwood (*Cornus florida*), (6) ash spp. (*Fraxinus* spp.), (7) red maple, and (8) bear oak (*Q. ilicifolia*).

I estimated stem density (stems/ha) for woody vegetation <1 m tall in each forest cover type, and changes in mean stem density for the following species and species groups: (1) blueberry (*Vaccinium* spp.), (2) white oak species, (3) red maple, (4) all oak species, (5) northern red oak, (6) flowering dogwood, (7) yellow poplar, (8) ash species, (9) mountain laurel, (10) brambles, and (11) birch spp. (*Betula* spp.).

For the cove hardwoods forest cover type, I estimated a tree species diversity index (H) and a measure of species evenness (H'). Species diversity at each sampling site was calculated as

$$H = \sum_{i=1}^{k} p_i \ln(p_i)$$

where k is the number of species, and p_i is the proportion of trees of species i. Species evenness was calculated as H/ln(k).

Big Meadows Data – Data of shrub coverage in Big Meadows were provided for three areas of the meadow (central, north, and south). The central area contained wetland habitat and was 6.17 ha, the north area was 17.1 ha, and the south area was 16.0 ha. Sixty-three randomly oriented 50-m transects were randomly located in the three areas in proportion to the size of each area (central - 10 transects, north - 27 transects, south - 26 transects). Areal coverage of tall shrubs was estimated using the line intercept method, and areal coverage of low shrubs was estimated using the point-intercept method at 1-m intervals along the transect (W. Cass, SNP, personal communication).

Areal coverage was estimated for the following species: panicled dogwood (*Cornus racemosa*), hazelnut (*Corylus americana* and *C. cornuta*), hawthorn (*Crataegus* spp.), black huckleberry (*Gaylussacia baccata*), maleberry (*Lyonia ligustrina*), black locust (*Robinia pseudoacacia*), brambles (*Rubus* spp.), broadleaf meadowsweet (*Spirea latifolia*), upland low blueberry (*Vaccinium pallidum*), squaw huckleberry (*Vaccinium stamineum*), and all shrub species combined. Meadow-wide estimates were calculated using the same stratified estimators described for the LTEMS data. Some species only occurred in the wetland (panicled dogwood, hazelnut, and broadleaf meadowsweet), or the upland meadow area (black locust), and thus areal coverage estimates for those species only were calculated for the areas in which they occurred.

Data from 1998 and 1999 were pooled because the 63 transects were sampled once over the two years and these years were prior to the treatment of mowing. All 63 sites were sampled in 2000, and were considered post-treatment data. In addition to estimating areal coverage for each species pre- and post-treatment, I calculated a paired difference in areal coverage pre- and post-treatment. I calculated 85% confidence intervals (Mahan 2000) for coverage estimates.

RESULTS

Tree Basal Area

The coefficient of variation (CV = SE/mean × 100%) of estimated changes in basal area for trees (>5 m tall) in plots paired over time were highly variable, and ranged from 15 - 548% among species in all forest cover types. Poor precision was expected for some situations (e.g., oak species in pine stands), and CVs were generally <40% for species in vegetation types where they were most abundant (e.g., changes in basal area of northern red oak in chestnut oak and northern red oak cover types). Results were similar for the precision of estimates of basal area at each sampling period.

Overall, the monitoring program detected large declines (95% CIs did not overlap 0) in the basal area of oaks and pines in certain vegetation types (see Tables 3 and 4). Increases were detected in basal area of yellow poplar in yellow poplar and black locust cover types, as well as in basal area of red maple in the northern red oak cover type.

Shrub and Sapling Stem Density

Few changes in stem density were detected for shrubs and saplings (vegetation 1 - 5 m tall). Most CVs were >50% (Range 31 - 1,169) and 95% confidence intervals were wide and most encompassed zero (Table 5). Likewise, *Rubus* spp. showed large increases, but none of the changes were statistically significant. Table 6 provides a summary of estimates of abundance (stems/ha), CVs, and 95% CIs for the first and second sampling periods for each forest cover type.

Seedling Stem Density

The results for seedlings (<1 m tall) were similar to those obtained for shrubs and saplings (Tables 7 and 8). Few changes were statistically different from zero, except when extreme changes occurred. For example, there was a decline in oak seedlings in chestnut oak stands; however, the precision of this estimate was poor (mean change = -7,114.7 stems/ha, 95% CI = -13,757 – -472).

Species Diversity in Cove Hardwoods

The tree species diversity index (H) exhibited little variability among sites in cove hardwood forest cover types. The index was 2.019 (CV = 3%, 80% CI = 1.944 – 2.098) at the first sampling period and H = 1.983 (CV = 3%, 80% CI = 1.910 – 2.060) at the second sampling period. The mean of paired differences declined between the two sampling periods (mean = -0.036, 80% CI = -0.068 – -0.005).

The measure of species evenness (H') also exhibited little variability. At the first sampling period H' = 0.840 (CV = 2%, 80% CI = 0.819 – 0.861), and at the second sampling period H' = 0.831 (CV = 2%, 80% CI = 0.806 – 0.856). The mean of paired differences was not different from zero (mean = -0.009, 80% CI = -0.019 – 0.001).

Forest Health

Flowering dogwood – All of the forest cover types, except cove hardwoods, exhibited declines in shrub stem density for flowering dogwood, although only the decline in the black locust forest cover type was significantly different from zero (mean change = -135.6 stems/ha, 95% CI = -257 – -14; Table 5). The CVs ranged from 31 to 61%. In contrast, the stem density of flowering dogwood seedlings was highly variable; the mean change ranged from -3,845.7 stems/ha to 1,589.3 stems/ha. Only in black locust forest cover types was the change significantly different from zero (mean change = 1,589.3 stems/ha, 95% CI = 1,370 – 1,808;

Table 7). The CVs ranged from 5 to 117%.

Tree-of-heaven – All forest cover types, except pine stands, exhibited an increase in shrub stem density for tree-of-heaven (mean change of 3.8 - 114.1 stems/ha), but none of these changes were statistically different from zero (CVs ranged from 64 - 80%; Tables 9 and 10). Results were similar for changes in stem density of seedlings in which CVs ranged from 69 - 4,372%.

Gypsy moth – The effects of gypsy moths should be most evident in the decline in basal area for oak species in chestnut oak and northern red oak forest cover types. In general, CVs for oaks in these cover types were <40% and declines were detected for northern red oaks and red oak species. White oaks did not exhibit a decline in the chestnut oak cover type, but did decline in the northern red oak cover type (Tables 3 and 4). Percent declines in basal area were 28 - 40% for oak species, except white oaks, in both forest cover types.

Big Meadows Shrub Cover

The coverage of shrubs in Big Meadow was quite low with percent cover generally <2% for most species (Table 12). Only panicled dogwood (16.2%) and broadleaf meadowsweet (18.5%) had mean coverage values >10% prior to mowing. Consequently, CVs of percent cover estimates were high (>50%), even for estimated declines in percent cover based on paired-difference estimates (Table 11). Precision of estimates for all shrub species combined, however, were reasonably precise for both estimates pre- and post-treatment and paired-transect differences (CVs < 18%).

Table 3. Change in mean basal area (m^2/ha) and total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type, Shenandoah National Park, 1988-2000.

Species	Forest Cover Type	Mean change (m^2/ha)	CV (%)	80% CI	Total change (m^2)	80% CI
Red oak species	Cove hardwoods	-0.66	66	-1.37 – 0.05	-7,621	-15,853 – 611
	Pine	0.71	61	0.05 – 1.38	3,048	195 – 5,902
	Chestnut oak	-2.23	39	-3.48 – -0.98	-84,592	-132,148 – -37,035
	Black locust	0.01	75	0.00 – 0.02	24	-6 – 54
	Northern red oak	-4.31	28	-6.02 – -2.60	-31,835	-44,473 – -19,197
	Yellow poplar	0.11	76	-0.05 – 0.27	1,342	-571 – 3,254
All oak species	Cove hardwoods	-2.51	64	-5.54 – 0.53	-29,112	-64,358 – 6,134
	Pine	0.06	425	-0.30 – 0.42	255	-1,276 – 1,785
	Chestnut oak	-3.17	26	-4.30 – -2.04	-120,485	-163,327 – -77,643
	Black locust	0.00	240	-0.01 – 0.02	11	-32 – 53
	Northern red oak	-6.39	15	-7.66 – -5.12	-47,173	-56,552 – -37,794
	Yellow poplar	-0.03	548	-0.39 – 0.32	-417	-4,735 – 3,900
Northern red oak	Cove hardwoods	0.43	66	-1.37 – 0.05	-7,621	-15,853 – 611
	Pine	0.22	157	-0.49 – 0.20	-614	-2,093 – 865
	Chestnut oak	0.88	38	-3.58 – -1.06	-87,951	-135,840 – -40,063
	Black locust	0.01	75	0.00 – 0.02	24	-6 – 54
	Northern red oak	1.21	28	-6.06 – -2.62	-32,051	-44,725 – -19,377
	Yellow poplar	0.08	92	-0.07 – 0.25	1,086	-791 – 2,963

Table 3. Continued.

Species	Forest Cover Type	Mean change (m^2/ha)	CV (%)	80% CI	Total change (m^2)	80% CI
White oak species	Cove hardwoods	1.54	84	-4.74 – 1.07	-21,322	-55,045 – 12,401
	Pine	0.12	68	0.00 – 0.36	765	0 – 1,530
	Chestnut oak	0.86	97	-2.10 – 0.33	-33,579	-79,720 – 12,562
	Black locust	0.00			0	
	Northern red oak	0.95	42	-3.61 – -0.92	-16,729	-26,674 – -6,783
	Yellow poplar	0.03	87	-0.02 – 0.09	392	-253 – 1,036
Yellow poplar	Cove hardwoods	0.15	50	0.04 – 0.26	1,709	439 – 2,978
	Pine	0.06	132	-0.06 – 0.18	251	-255 – 757
	Chestnut oak	0.06	76	0.00 – 0.12	2,261	-156 – 4,678
	Black locust	0.18	20	0.11 – 0.25	575	354 – 796
	Northern red oak	0.04	100	-0.03 – 0.12	327	-208 – 862
	Yellow poplar	2.51	43	0.98 – 4.04	30,220	11,822 – 48,618
Red maple	Cove hardwoods	-0.29	109	-0.89 – 0.30	-3376	-10,291 – 3,539
	Pine	0.61	43	0.11 – 1.12	2,633	476 – 4,790
	Chestnut oak	0.56	86	-0.93 – 2.05	21,322	-35,336 – 77,980
	Black locust	0.05	165	-0.10 – 0.20	155	-328 – 639
	Northern red oak	0.19	35	0.10 – 0.28	1,384	724 – 2,044
	Yellow poplar	0.12	76	-0.02 – 0.25	1,399	-235 – 3,032

Table 3. Continued.

Species	Forest Cover Type	Mean change (m^2/ha)	CV (%)	80% CI	Total change (m^2)	80% CI
Virginia and pitch pine	Pine	-11.19	26	-15.69 – -6.69	-47,979	-67,274 – -28,683
Black locust	Cove hardwoods	-0.28	40	-0.43 – -0.12	-3,228	-5,014 – -1,441
	Pine	-0.07	104	-0.20 – 0.06	-291	-858 – 277
	Chestnut oak	-0.13	66	-0.28 – 0.03	-4,813	-10,807 – 1,180
	Black locust	-0.71	50	-1.30 – -0.13	-2,278	-4,144 – -412
	Northern red oak	-0.08	87	-0.19 – 0.03	-602	-1,405 – 202
	Yellow poplar	-0.90	58	-1.76 – -0.04	-10,830	-21,161 – -498
Black birch	Cove hardwoods	-0.47	43	-0.80 – -0.14	-5446	-9,271 – -1,621
	Pine	0.26	52	0.00 – 0.51	1,107	20 – 2,193
	Chestnut oak	0.12	75	-0.01 – 0.25	4,505	-376 – 9,386
	Black locust	0.02	204	-0.09 – 0.12	53	-278 – 384
	Northern red oak	0.05	79	-0.01 – 0.11	394	-54 – 841
	Yellow poplar	-0.18	121	-0.54 – 0.18	-2,205	-6,564 – 2,155

Table 4. Total basal area (m^2) for each tree (>5 m tall) species or species group, by forest cover type and sampling period, Shenandoah National Park, 1987-2000.

		First sampling period			Second sampling period		
Species	Forest Cover Type	Total basal area (m^2)	CV	80% CI	Total basal area (m^2)	CV	80% CI
Red oak species	Cove hardwoods	34,386	70	12,254 – 96,492	26,764	89	7,697 – 93,071
	Pine	6,417	60	2,743 – 15,009	9,465	60	4,067 – 22,030
	Chestnut oak	252,463	31	164,274 – 387,996	163,239	50	82,968 – 321,175
	Black locust	96	66	36 – 258	120	68	44 – 330
	Northern red oak	114,822	33	73,123 – 180,299	82,987	34	51,725 – 133,142
	Yellow poplar	3,608	100	755 – 17,244	4,950	92	1,135 – 21,589
All oak species	Cove hardwoods	72,593	49	30,170 – 174,670	43,481	69	13,442 – 140,647
	Pine	21,211	63	9,346 – 48,139	21,466	63	9,483 – 48,592
	Chestnut oak	1,110,439	9	977,229 – 1,261,807	987,472	13	826,223 – 1,180,190
	Black locust	466	76	154 – 1,405	477	71	168 – 1,355
	Northern red oak	176,444	14	145,704 – 213,670	129,271	21	97,524 – 171,352
	Yellow poplar	11,297	29	6,562 – 19,449	10,880	51	4,400 – 26,900
Northern red oak	Cove hardwoods	34,386	70	12,254 – 96,492	26,764	89	7,697 – 93,071
	Pine	2,434	68	950 – 6,234	1,820	76	647 – 5,120
	Chestnut oak	234,259	37	140,725 – 389,961	141,676	56	66,729 – 300,799
	Black locust	96	66	36 – 258	120	68	44 – 330
	Northern red oak	109,026	35	67,880 – 175,113	76,975	37	46,627 – 127,078
	Yellow poplar	3,608	100	755 – 17,244	4,694	98	997 – 22,107

Table 4. Continued

Species	Forest Cover Type	First sampling period: Total basal area (m^2)	CV	80% CI	Second sampling period: Total basal area (m^2)	CV	80% CI
White oak species	Cove hardwoods	38,039	64	12,616 – 114,693	16,717	92	3,830 – 72,960
	Pine	11,235	70	4,425 – 28,528	12,001	69	4,802 – 29,993
	Chestnut oak	784,385	15	634,108 – 970,275	752,956	18	582,436 – 973,399
	Black locust	0			0		
	Northern red oak	59,874	51	30,395 – 117,941	43,145	53	21,381 – 87,060
	Yellow poplar	5,539	80	1,472 – 20,842	5,930	80	1,566 – 22,454
Yellow poplar	Cove hardwoods	11,684	86	3,893 – 35,066	13,392	87	4,416 – 40,611
	Pine	262	100	73 – 940	513	100	143 – 1,838
	Chestnut oak	21,100	92	6,942 – 64,135	23,361	96	7,479 – 72,969
	Black locust	3,905	22	2,607 – 5,848	4,480	18	3,185 – 6,300
	Northern red oak	318	100	81 – 1,245	645	100	165 – 2,523
	Yellow poplar	236,810	22	174,124 – 322,064	267,030	25	187,569 – 380,153
Red maple	Cove hardwoods	30,564	82	7,861 – 118,844	27,189	78	7,463 – 99,050
	Pine	3,099	84	784 – 12,258	5,732	80	1,520 – 21,621
	Chestnut oak	52,908	74	6,876 – 407,078	73,855	77	9,102 – 599,297
	Black locust	3,342	56	1,251 – 8,927	3,007	59	1,079 – 8,377
	Northern red oak	5,194	45	2,897 – 9,314	6,578	46	3,601 – 12,015
	Yellow poplar	23,468	42	12,731 – 43,261	24,867	43	13,294 – 46,516

Table 4. Continued

Species	Forest Cover Type	First sampling period: Total basal area (m^2)	CV	80% CI	Second sampling period: Total basal area (m^2)	CV	80% CI
Virginia and pitch pine	Pine	73,806	27	42,585 – 106,959	23,572	63	7843 – 48,535
Black locust	Cove hardwoods	32,768	62	14,764 – 72,727	29,540	63	13,211 – 66,050
	Pine	1,205	68	375 – 3,874	915	100	190 – 4,396
	Chestnut oak	19,257	80	5,116 – 72,476	14,443	84	3,625 – 57,533
	Black locust	39,389	5	36,280 – 42,765	36,959	8	32,550 – 41,966
	Northern red oak	3,361	84	1,102 – 10,248	2,759	100	770 – 9,888
	Yellow poplar	19,784	56	8,376 – 46,728	8,954	72	3,108 – 25,792
Black Birch	Cove hardwoods	24,795	52	11,200 – 54,892	19,349	66	7,272 – 51,483
	Pine	2,122	70	647 – 6,955	3,228	69	1,002 – 10,392
	Chestnut oak	12,810	80	4,633 – 35,419	16,971	86	5,805 – 49,611
	Black locust	398	114	24 – 6,617	650	100	50 — 8,425
	Northern red oak	3,186	73	1,240 – 8,183	3,580	71	1,424 – 8,995
	Yellow poplar	17,474	65	6,624 – 46,088	15,269	61	6,105 – 38,185

Table 5. Change in mean count (stems/ha) of shrubs and saplings (1 - 5 m tall) for each species or species group, by forest cover type, Shenandoah National Park, 1988- 2000.

Species	Forest Cover Type	Mean change	CV	80% CI
Ash species	Cove hardwoods	-63.1	58	-132 – 6
	Pine	56.3	87	-36 – 149
	Chestnut oak	1.7	194	-3 – 6
	Black locust	-16.1	141	-53 – 21
	Northern red oak	-5.5	1169	-105 – 94
	Yellow poplar	-284.2	63	-577 – 8
Flowering dogwood	Cove hardwoods	0		
	Pine	-484.5	55	-920 – -49
	Chestnut oak	-137.2	59	-290 – 16
	Black locust	-135.6	31	-214 – -57
	Northern red oak	-94.0	61	-203 – 15
	Yellow poplar	-321.3	53	-581 – -62
Spicebush	Cove hardwoods	1,130.1	38	427 – 1,833
	Pine	240.8	100	-128 – 610
	Chestnut oak	13.9	205	-27 – 55
	Black locust	444.0	37	174 – 714
	Northern red oak	61.1	126	-65 – 187
	Yellow poplar	2,873.2	49	544 – 5,202

Table 5. Continued

Species	Forest Cover Type	Mean change	CV	80% CI
Sassafrass	Cove hardwoods	-7.2	100	-21 – 6
	Pine	201.3	58	30 – 372
	Chestnut oak	215.2	46	69 – 362
	Black locust	208.3	57	-159 – 572
	Northern red oak	4.2	573	-33 – 42
	Yellow poplar	-10.8	197	-43 – 22
Rubus spp.	Cove hardwoods	61.6	77	-28 – 151
	Pine	425.3	62	45 – 806
	Chestnut oak	881.4	77	-1,198 – 2,961
	Black locust	351.8	50	62 – 642
	Northern red oak	4,112.9	65	265 – 7,960
	Yellow poplar	111.6	88	-50 – 273
Mountain laurel	Cove hardwoods	0		
	Pine	508.8	71	-1,334 – 2,351
	Chestnut oak	331.3	38	115 – 507
	Black locust	0		
	Northern red oak	167.2	76	-12 – 346
	Yellow poplar	-35.3	100	-93 – 23
Scrub oak	Pine	-199.2	97	-470 – 71

Table 6. Stem density (stems/ha) for shrub and sapling (1 - 5 m tall) species, by forest cover type and sampling time, Shenandoah National Park, 1988-2000.

		First sampling period			Second sampling period		
Species	Forest Cover Type	Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Ash species	Cove hardwoods	157.3	49	66 – 376	94.2	48	40 – 222
	Pine	18.7	100	4 – 89	74.9	90	18 – 320
	Chestnut oak	46.1	71	18 – 116	47.8	71	19 – 120
	Black locust	97.0	25	65 – 145	88.9	32	53 – 148
	Northern red oak	174.6	33	106 – 287	169.0	51	81 – 352
	Yellow poplar	405.1	55	175 – 936	120.9	41	63 – 231
Flowering dogwood	Cove hardwoods	15.7	50	8 – 30	15.7	50	8 – 30
	Pine	536.1	57	225 – 1,275	51.6	100	13 – 202
	Chestnut oak	270.1	42	127 – 576	132.9	48	56 – 313
	Black locust	202.8	15	153 – 269	67.2	46	30 – 153
	Northern red oak	278.9	47	120 – 649	184.9	41	89 – 386
	Yellow poplar	329.5	50	159 – 681	8.3	100	2 – 30
Spicebush	Cove hardwoods	463.8	28	296 – 727	1,593.9	32	959 – 2,650
	Pine	0			240.8	100	67 – 862
	Chestnut oak	12.7	82	5 – 36	26.7	100	8 – 88
	Black locust	521.7	79	166 – 1,640	553.3	39	300 – 1,022
	Northern red oak	30.5	46	15 – 62	91.6	94	25 – 338
	Yellow poplar	1490.3	41	783 – 2837	4,363.5	43	2,238 – 8,508

Table 6. Continued

Species	Forest Cover Type	First sampling period			Second sampling period		
		Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Sassafrass	Cove hardwoods	14.4	100	3 – 69	7.2	100	2 – 35
	Pine	138.3	58	62 – 306	339.6	34	208 – 554
	Chestnut oak	250.4	42	139 – 452	465.6	40	263 – 825
	Black locust	69.9	81	8 – 617	306.0	66	48 – 1,958
	Northern red oak	78.2	48	39 – 157	82.4	73	30 – 226
	Yellow poplar	24.7	60	11 – 58	13.9	72	5 – 37
Rubus species	Cove hardwoods	0			61.6	77	17 – 223
	Pine	0			425.3	62	187 – 968
	Chestnut oak	0			881.4	77	109 – 7,144
	Black locust	26.4	75	9 – 79	378.2	46	185 – 772
	Northern red oak	26.8	100	8 – 89	4,139.8	65	1,762 – 9,727
	Yellow poplar	39.0	88	11 – 134	150.6	54	66 – 346
Mountain laurel	Cove hardwoods	0			0		
	Pine	2,228.2	35	1,168 – 4,249	1,804.5	32	1,321 – 5,673
	Chestnut oak	1,116.3	35	696 – 1,792	1,638.1	33	1,046 – 2,566
	Black locust	0			0		
	Northern red oak	344.2	66	146 – 810	511.4	49	267 – 981
	Yellow poplar	35.3	100	9 – 138	0		

Table 6. Continued.

Species	Forest Cover Type	First sampling period			Second sampling period		
		Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Scrub Oak	Pine	360.9	58	171 – 762	161.7	54	79 – 330

Table 7. Change in stem density (stems/ha) of seedlings (<1 m tall), by species or species group and forest cover type, Shenandoah National Park, 1988-2000.

Species	Forest Cover Type	Mean change	CV	80% CI
Northern red oak	Cove hardwoods	-207.4	105	-879 – 464
	Pine	-182.7	283	-1,158 – 793
	Chestnut oak	-2,222.6	53	-3,972 – -473
	Black locust	-522.0		[a]
	Northern red oak	631.2	314	-2,110 – 3,373
	Yellow poplar	197.0	235	-514 – 908
White oak species	Cove hardwoods	-66.7	100	-192 – 59
	Pine	2,363.9	33	1,265 – 3,463
	Chestnut oak	-5,225.6	42	-8,203 – -2,248
	Black locust	348.0		[a]
	Northern red oak	-1,027.1	83	-2,336 – 282
	Yellow poplar	-318.1	100	-839 – 203
Oak species	Cove hardwoods	-395.0	60	-839 – 49
	Pine	5,106.7	67	42 – 10,171
	Chestnut oak	-7,114.7	44	-11,892 – 2,338
	Black locust	-174.0		[a]
	Northern red oak	552.0	465	-2,972 – 4,076
	Yellow poplar	131.3	379	-632 – 895

Table 7. Continued.

Species	Forest Cover Type	Mean change	CV	80% CI
Red maple	Cove hardwoods	13,185.5	64	296 – 26,075
	Pine	10,976.9	55	-444 – 22,398
	Chestnut oak	16,175.1	42	5,856 – 26,494
	Black locust	-7,583.9	97	-22,169 – 6,461
	Northern red oak	3,164.2	95	-1,772 – 8,100
	Yellow poplar	3,794.2	123	-3,112 – 10,701
Ash species	Cove hardwoods	3,278.7	69	65 – 6,492
	Pine	842.4	92	-430 – 2,114
	Chestnut oak	235.1	145	-255 – 725
	Black locust	-17,496.3	2	-17,967 – -17,026
	Northern red oak	-1,295.0	73	-2,739 – 149
	Yellow poplar	-958.8	200	-3,782 – 1,864
Birch species	Cove hardwoods	399.9	215	-1,221 – 2,021
	Pine	-1715.5	166	-6,379 – 2,948
	Chestnut oak	632.5	175	-1,182 – 2,447
	Black locust	0		
	Northern red oak	2573.3	83	-712 – 5,859
	Yellow poplar	-954.2	64	-1,951 – 43

Table 7. Continued.

Species	Forest Cover Type	Mean change	CV	80% CI
Yellow poplar	Cove hardwoods	1,528.8	72	-280 – 3,338
	Pine	139.8	100	-74 – 354
	Chestnut oak	2,816.5	68	-3,110 – 8,743
	Black locust	230.5	251	-718 – 1,179
	Northern red oak	687.8	73	-130 – 1,506
	Yellow poplar	274.4	315	-1,051 – 1,599
Flowering dogwood	Cove hardwoods	81.5	100	-72 – 235
	Pine	-3,845.7	69	-8,820 – 1,128
	Chestnut oak	941.6	63	118 – 1,765
	Black locust	1,589.3	5	1,448 – 1,731
	Northern red oak	-1,185.2	117	-3,808 – 1,437
	Yellow poplar	-2,140.7	86	-4,949 – 668
Mountain laurel	Cove hardwoods	0		
	Pine	-38,099.5	78	-86,568 – 10,369
	Chestnut oak	-4,399.6	108	-11,210 – 2,411
	Black locust	0		
	Northern red oak	1,120.3	47	121 – 2,120
	Yellow poplar	0		

Table 7. Continued.

Species	Forest Cover Type	Mean change	CV	80% CI
Vaccinium species	Cove hardwoods	0		
	Pine	-98,466.1	52	-173,000 – 23,528
	Chestnut oak	18,680.4	88	-31,753 – 69,113
	Black locust	0		
	Northern red oak	-2,927.0	224	-12,621 – 6,767
	Yellow poplar	0		
Rubus species	Cove hardwoods	730.0	149	-942 – 2,402
	Pine	11,869.5	43	4,462 – 19,277
	Chestnut oak	3,241.1	49	232 – 6,250
	Black locust	10,148.4	8	8,949 – 11,348
	Northern red oak	5,784.5	32	3,210 – 8,359
	Yellow poplar	4,482.5	38	1,939 – 7,026

[a]No standard error could be estimated because there was no replication of plots in the strata in which stems were counted.

Table 8. Stem density (stems/ha) for seedlings (<1 m tall) by species or species group and forest cover type, Shenandoah National Park, 1988-2000.

		First sampling period			Second sampling period		
Species	Forest Cover Type	Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Northern red oak	Cove hardwoods	841.9	55	173 – 4,105	634.6	65	101 – 3,980
	Pine	604.3	80	160 – 2,281	421.6	64	141 – 1,265
	Chestnut oak	3,593.4	37	2,122 – 6,084	1,357.3	35	820 – 2,247
	Black locust	696.0		[a]	174.0		[a]
	Northern red oak	4,693.6	21	3,524 – 6,251	5,324.8	36	3,284 – 8,633
	Yellow poplar	446.2	58	196 – 1,015	643.2	60	275 – 1,503
White oak species	Cove hardwoods	66.7	100	14 – 320	0		
	Pine	5,411.8	66	2,322 – 12,614	7,775.7	50	4,003 – 15,104
	Chestnut oak	19,999.3	23	14,666 – 27,272	14,760.2	24	10,652 – 20,453
	Black locust	0		[a]	348.0		[a]
	Northern red oak	5,375.3	48	2,681 – 10,777	4,348.2	49	2,132 – 8,869
	Yellow poplar	466.8	75	156 – 1,397	148.7	100	38 – 581
Oak species	Cove hardwoods	1,029.6	48	440 – 2,411	634.6	65	206 – 1,955
	Pine	7,826.5	47	4,060 – 15,087	12,933.1	39	7,391 – 22,630
	Chestnut oak	24,660.0	24	17,193 – 35,370	17,518.3	22	12,598 – 24,360
	Black locust	696.0		[a]	522.0		[a]
	Northern red oak	10,994.1	32	7,183 – 16,828	11,546.1	30	7,718 – 17,272
	Yellow poplar	1,220.7	46	623 – 2,391	1,352.0	28	890 – 2,053

Table 8. Continued.

Species	Forest Cover Type	First sampling period			Second sampling period		
		Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Red maple	Cove hardwoods	3,171.8	70	1,205 – 8,346	16,357.3	52	7,733 – 34,600
	Pine	5,521.2	57	2,025 – 15,053	16,498.2	53	6,507 – 41,830
	Chestnut oak	6,527.2	22	4,686 – 9,092	22,715.7	32	14,157 – 36,448
	Black locust	13,032.2	71	3,880 – 43,776	6,034.8	34	3,248 – 11,213
	Northern red oak	3,985.4	22	2,783 – 5,708	7,149.6	53	3,183 – 16,058
	Yellow poplar	12,940.6	26	8,932 – 18,749	16,734.9	31	10,660 – 26,271
Ash species	Cove hardwoods	6,710.0	39	3,959 – 11,372	9,988.7	25	7,090 – 14,073
	Pine	982.2	80	309 – 3,120	1,824.6	85	542 – 6,137
	Chestnut oak	479.3	60	216 – 1,064	714.4	60	323 – 1,582
	Black locust	21,948.6	2	21,390 – 22,522	4,595.0	6	4,160 – 5,076
	Northern red oak	3,765.1	34	2,283 – 6,208	2,470.2	45	1,282 – 4,760
	Yellow poplar	78,62.1	35	4,747 – 13,022	6,903.3	26	4,729 – 10,077
Birch species	Cove hardwoods	1,298.5	68	406 – 4,158	1,698.4	96	370 – 7,790
	Pine	3,394.0	92	945 – 12,183	1,678.5	40	897 – 3,141
	Chestnut oak	1,118.6	29	702 – 1,782	1,724.2	67	638 – 4,657
	Black locust	571.0	100	181 – 1,803	0		
	Northern red oak	1,760.1	96	510 – 6,078	4,333.4	88	1,353 – 13,883
	Yellow poplar	954.2	64	366 – 2,485	0		

Table 8. Continued.

Species	Forest Cover Type	First sampling period			Second sampling period		
		Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Yellow poplar	Cove hardwoods	162.9	100	42 – 636	1,691.8	69	608 – 4,705
	Pine	0			139.8	100	39 – 501
	Chestnut oak	106.6	63	18 – 635	2,923.1	66	457 – 18,697
	Black locust	586.8	59	239 – 1,440	960.1	60	387 – 2,383
	Northern red oak	0			687.8	73	237 – 1,997
	Yellow poplar	737.6	87	233 – 2,339	1,012.0	51	482 – 2,123
Flowering dogwood	Cove hardwoods	0			81.5	100	17 – 391
	Pine	4,000.5	69	1,231 – 13,003	154.8	100	32 – 743
	Chestnut oak	985.4	59	457 – 2,124	1,927.0	43	1,083 – 3,429
	Black locust	150.6	50	62 – 366	1,740.0		[a]
	Northern red oak	5,738.7	34	3,053 – 10,787	4,553.5	13	3,574 – 5,801
	Yellow poplar	2,935.8	55	1,329 – 6,485	795.1	100	222 – 2,849
Mountain laurel	Cove hardwoods	0			0		
	Pine	43,779.1	69	15,754 – 121,657	5,679.6	42	2,936 – 10,988
	Chestnut oak	8,031.9	60	3,608 – 17,878	3,632.4	33	2,272 – 5,807
	Black locust	0			0		
	Northern red oak	1,267.4	46	553 – 2,904	2,387.7	44	1,086 – 5,250
	Yellow poplar	0			0		

Table 8. Continued.

Species	Forest Cover Type	First sampling period			Second sampling period		
		Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Vaccinium species	Cove hardwoods	0			0		
	Pine	176,973.9	36	36 – 106,336	78,507.8	27	52,927 – 116,452
	Chestnut oak	41,484.5	58	58 – 7,875	60,164.9	66	9,356 – 386,906
	Black locust	0			0		
	Northern red oak	20,589.2	33	33 – 12,749	17,662.2	39	10,080 – 30,948
	Yellow poplar	0			0		
Rubus species	Cove hardwoods	1,375.1	86	440 – 4,293	2,105.1	36	1,239 – 3,577
	Pine	3,965.9	71	1,579 – 9,960	15,835.4	40	9,137 – 27,444
	Chestnut oak	196.2	71	59 – 652	3,437.3	45	1,519 – 7,778
	Black locust	2,414.4	31	1,538 – 3,790	12,848.3	9	11,210 – 14,726
	Northern red oak	1,179.8	49	615 – 2,262	6,964.3	30	4,610 – 10,521
	Yellow poplar	1,340.5	67	547 – 3,288	5,823.0	37	3,415 – 9,928

[a]No standard error could be estimated because there was no replication of plots in the strata in which stems were counted.

Table 9. Change in mean density (stems/ha) of saplings and seedlings for tree-of-heaven (*Ailanthus altissima*), Shenandoah National Park, 1988-2000.

Size class	Forest Cover Type	Mean change	CV	80% CI
Saplings	Cove hardwoods	143.0	80	-32 – 318
	Pine	0		
	Chestnut oak	20.7	71	-1 – 43
	Black locust	55.7	70	-18 – 130
	Northern red oak	3.8	100	-2 – 10
	Yellow poplar	110.2	64	6 – 215
Seedlings	Cove hardwoods	-3,368.2	75	-7,499 – 762
	Pine	1,398.4	69	-77 – 2,874
	Chestnut oak	-7.7	4,372	-504 – 489
	Black locust	-119.7	2,170	-5,016 – 4,777
	Northern red oak	206.4	74	-29 – 442
	Yellow poplar	-1,976.3	213	-8,185 – 4,233

Table 10. Stem density (stems/ha) of tree-of-heaven (*Ailanthus altissima*) for saplings (1 - 5 m tall) and seedlings (<1 m tall) by forest cover type and sampling period in Shenandoah National Park, 1988-2000.

		First sampling period			Second sampling period		
Size class	Forest Cover Type	Stems/ha	CV	80% CI	Stems/ha	CV	80% CI
Shrubs	Cove hardwoods	21.7	100	6 – 78	164.7	64	67 – 403
	Pine	0			0		
	Chestnut oak	0			20.7	71	8 – 53
	Black locust	4.2	100	1 – 20	59.9	72	18 – 203
	Northern red oak	0			3.8	100	1 – 15
	Yellow poplar	34.1	63	14 – 80	144.3	58	65 – 320
Seedlings	Cove hardwoods	5,288.0	78	1,709 – 16,360	1,919.8	88	553 – 6,668
	Pine	0			1,398.4	69	538 – 3,633
	Chestnut oak	2,66.5	100	78 – 910	258.8	74	98 – 686
	Black locust	4,137.3	64	1,367 – 12,520	4,017.6	19	2,795 – 5,774
	Northern red oak	0			206.4	74	75 – 571
	Yellow poplar	5,297.9	75	1,981 – 14,167	3,321.5	77	1,216 – 9,076

Table 11. Decline in percent cover (paired-plot differences), by species and for all species combined, from pre- (1998-99) to post-treatment (2000) in Big Meadow, Shenandoah National Park.

Species	Mean decline in % cover	CV	85% CI
Hawthorn spp.	0.38	70.6	-0.15 – 0.92
Black huckleberry	0.31	118.8	-0.36 – 0.98
Maleberry	2.73	33.1	1.08 – 4.37
Rubus spp.	-0.02	125.8	-0.08 – 0.03
Upland low blueberry	1.92	31.9	0.81 – 3.03
Squaw huckleberry	5.18	22.4	3.07 – 7.30
Black locust	0.12	95.0	-0.09 – 0.33
Panicled dogwood	11.60	53.6	1.8 – 21.4
Hazelnut spp.	0.60	71.7	-0.1 – 1.2
Broadleaf meadowsweet	18.00	54.2	2.6 – 33.4
All shrub spp.	15.12	13.5	11.3 – 18.9

Table 12. Percent cover, by species, pre-treatment (1998-99) and post-treatment (2000) in the Big Meadow, Shenandoah National Park.

	Pre-treatment			Post-treatment		
Species	% cover	CV	85% CI	% cover	CV	85% CI
Hawthorn spp.	0.39	67.3	0.18 – 0.89	0.01	100.0	0.00 – 0.05
Black huckleberry	0.55	53.6	0.29 – 1.01	0.24	93.2	0.09 – 0.63
Maleberry	4.70	21.6	3.63 – 6.08	1.97	31.2	1.37 – 2.84
Rubus spp	0.01	77.0	0.00 – 0.02	0.03	100.0	0.01 – 0.08
Upland low blueberry	1.95	31.2	1.36 – 2.82	0.04	81.3	0.02 – 0.09
Squaw huckleberry	7.45	18.6	5.97 – 9.30	2.27	26.8	1.65 – 3.11
Black locust	0.15	75.9	0.06 – 0.33	0.03	81.2	0.01 – 0.06
Panicled dogwood	16.2	55.4	8.17 – 32.14	4.56	62.0	2.94 – 9.71
Hazelnut spp.	0.66	74.5	0.27 – 1.60	0.09	100.0	0.03 – .28
Broadleaf meadowsweet	18.46	54.9	9.34 – 36.48	0.45	98.5	0.15 – 1.33
All shrub spp.	20.92	12.3	18.03 – 24.27	5.80	17.4	4.72 – 7.14

Part II - Estimates of Statistical Power to Meet Objectives

INTRODUCTION

Estimating statistical power to detect changes in basal area or stem density can be used to assess whether current sampling efforts can meet stated objectives. I used estimates of means and variances obtained in Part I to estimate the statistical power to detect a range of changes in basal area and stem density for specific sample sizes. Statistical power was estimated for the following objectives:

1. Data collected for the LTEMS program should ensure a 90% probability of detecting a 50% change in the density of any one species of tree within any one forest cover type over a 5-year period ($\alpha = 0.20$). I assessed the ability of current sampling efforts to meet this objective by calculating power curves for tree basal area, shrub stem density, and seedling stem density.
2. Data collected for the LTEMS program should ensure an 80% probability of detecting a 20% change in the coverage of a particular exotic species parkwide over a 5-year period ($\alpha = 0.20$). I assessed the ability of the current LTEMS program at SNP to meet this objective using the power curves calculated above for changes in sapling and seedling stem density of tree-of-heaven.
3. Data collected for the LTEMS program should ensure an 80% probability of detecting a 20% change parkwide in species affected by disease or insects over a 5-year period ($\alpha = 0.20$). I assessed the ability of the current LTEMS program at SNP to meet this objective using the power curves calculated above for changes in

shrub and seedling stem density of flowering dogwood and tree basal area of all oak species.

4. Monitoring of shrub coverage at Big Meadow should ensure a 95% probability of detecting a 40% reduction in shrub coverage over a 5-year period ($\alpha = 0.15$). I estimated the statistical power to detect these changes using program TRENDS.

Estimating sample sizes in a stratified sampling design is difficult if the strata are not the same size, which is why I used Satterthwaite df which weights the variances of each stratum by its size (ha). If all strata are the same size the Satterthwaite df reduces to n - L, where n is the number of sampling plots and L is the number of strata. As an example, if all strata were the same size in the northern red oak forest cover type (21 plots, Table 1), of which there were 6 strata (3 elevation x 2 moisture), the degrees of freedom would have been 15. However, hectares among these strata ranged from 501.9 - 1,702.8 and the moist aspect - low elevation stratum contained only 1 plot, which does not permit the estimation of variance for that stratum. Consequently, the Satterthwaite df was only 10 for basal area of red maple in this cover type.

Regardless of the variability in sample sizes for various species and forest cover types, when using the power curves created in this report to make inferences about sample sizes required, the following relationship is a useful starting point for estimating sample size requirements

$$n = 4 \times Satterthwaite\ df\ .$$

This is based on the fact that the average Satterthwaite df $\cong$4 (for basal area and stem densities in Part I of this report) and the average number of plots per forest cover type was 16.

METHODS

I estimated statistical power to detect changes (mean difference of paired plots between sampling periods) in tree basal area, shrub and sapling stem density, and stem density of seedlings. Because the variance of these parameters was positively correlated with the mean, I first modeled the standard deviation (SD) as a linear function of the mean change. From Part I, I obtained means, standard errors, and Satterthwaite df for individual species in all forest cover types, which I used to construct a linear model. From this model I could predict the standard error for a given absolute value of the change in the parameter of interest. For changes in basal area or stem density beyond the limits of the linear model, I used the estimate of standard deviation from the largest change in basal area or stem density in the model.

I assumed the distribution of mean change in the parameter of interest (θ; i.e., basal area or stem density) could be described by a *t* distribution, in which the SE(θ) was a function of the mean. Figure 1 is an example of the SAS program used to calculate the power of detecting a given difference in θ and Satterthwaite df. In the simulations, alpha = 0.20, Satterthwaite df ranged from two to 10, basal area ranged from 0 to nine m^2/ha, shrub/sapling stem density ranged from 0 to 5,000 stems/ha, and seedling stem density ranged from 0 to 70,000 stems/ha.

Program TRENDS (Gerrodette 1993) provides estimates of statistical power to detect changes in a trend. I used this program to estimate the power to detect a decline in shrub coverage at the rate of 9.8% per year (40% in 5 years). For inputs into Program TRENDS I used CV = 13%, 20%, and 25%, $\alpha = 0.15$, 1-tailed *t*-test, exponential decline in shrub coverage, and CV was directly proportional to shrub coverage. I estimated power for 3 - 10 years of sampling.

```
***************************************************
*
*     This SAS program estimates statistical power
*           to detect changes in basal area (BA)
*
*
*     Written by Duane R. Diefenbach, July 2001
***************************************************;

data power;

 do df = 2 to 10 ;          * Satterthwaite degrees of freedom;
     do diff=0 to 9 by 1;  * Change in basal area (m^2/ha);
      sd0=.11368;               * Std Dev of estimate of no change in BA;
      sd=.11368+.89710*diff;    * Std Dev for given mean change in BA;
      if diff>4 then sd=.11368+.8971*4; * Std Dev beyond the regression model;
       se=sd/sqrt(df); se0=sd0/sqrt(df); *Std Errors;
       cv=int(se/diff*100);

       nullhigh=tinv(.9,df); nulllow=tinv(.1,df); *t-statistics for null dist;
       low=nulllow+diff/se; high=nullhigh+diff/se;*t-stats for the change;
         powerlow=probt(low,df); powerhigh=1-probt(high,df);
         power=int((powerlow+powerhigh)*1000)/10; *Power or 1-Beta;
         output;
 end; end;

proc sort; by diff df;
proc print;
 title 'Power to Detect Changes in BA';
 var diff df se0 se power;
proc plot;
 plot power*df=diff;
 quit;
run;
```

Figure 1. SAS program used to estimate statistical power for basal area. Power analyses for stem density simply used different coefficients to estimate variables SD0 and SD, as well as different ranges for variable DIFF.

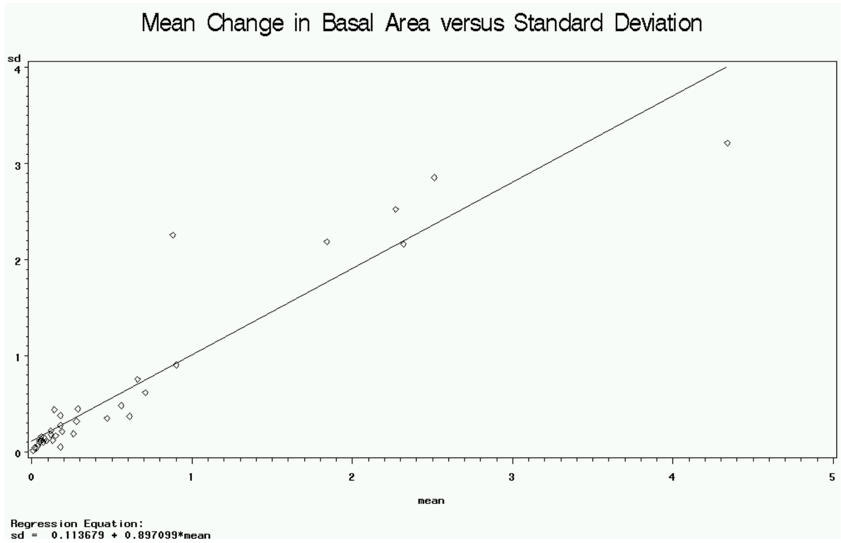
RESULTS

The average Satterthwaite df = 4 for estimates of tree basal area and stem density within each forest cover type presented in Part I of this report. Thus, the graphs of estimated statistical power for changes in basal area and stem density at Satterthwaite df = 4 provide a measure of the statistical power of the current sampling effort for the LTEMS at SNP.

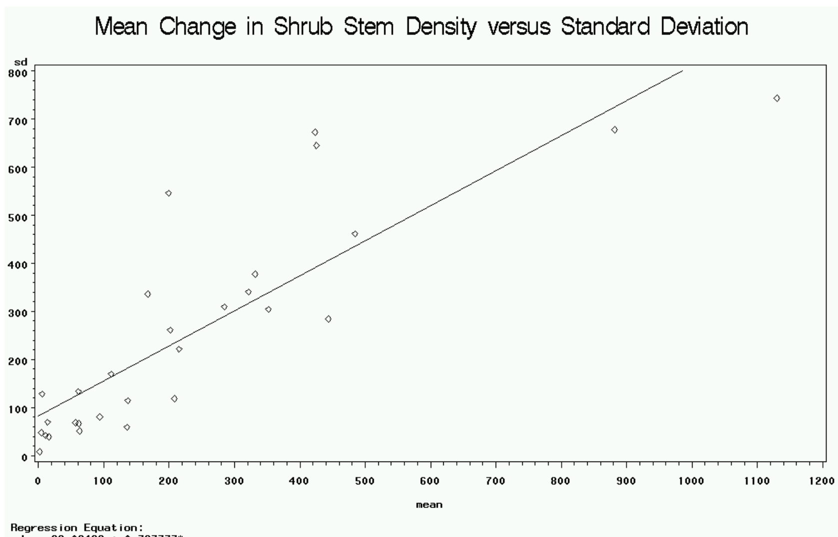
I was able to model standard deviation as a function of mean change in basal area and stem densities. The relationship between the mean change in tree basal area (BA) and standard deviation (SD) was described by the equation SD = 0.11368 + 0.89710 * BA ($F_{1,33}$ = 238.9, P < 0.001, R^2 = 0.88). The relationship between the mean change in shrub and sapling stem density (STEM) and standard deviation was described by the equation SD = 83.03489 + 0.72778 * STEM ($F_{1,27}$ = 72.7, P < 0.001, R^2 = 0.73). The relationship between the mean change in seedling stem density and standard deviation was described by the equation SD = 868.83149 + 1.01217 * REGEN ($F_{1,41}$ = 106.8, P < 0.001, R^2 = 0.72). Figure 2 provides scatterplots of the data along with the fitted regression line.

Tree basal area – The estimates of statistical power indicated that current sample sizes (4 Satterthwaite df) would permit detection of a change of 6 m^2/ha with 90% power, which represents a 10% change at 60 m^2/ha, 20% change at 30 m^2/ha, and 50% at 12 m^2/ha. Figure 3 presents the estimates of power for increasing sample sizes and changes in basal area. Because most basal area measurements are >20 m^2/ha for species in their primary forest cover types (e.g., yellow poplar in cove hardwoods, northern red oak in chestnut oak cover type, etc.), current sampling effort should have $\geq$90% power to detect changes in basal area of 50% for dominant species.

(A)



(B)



(C)

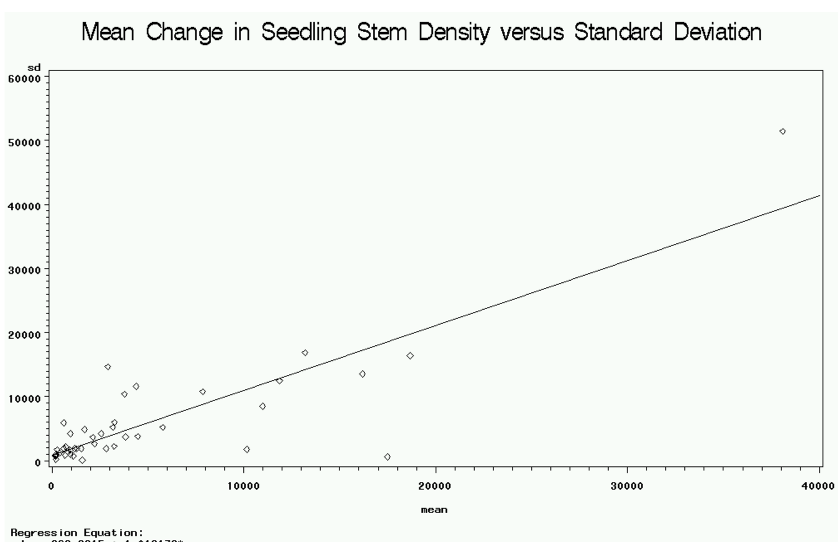


Figure 2. Scatterplot with regression line for the relationship between standard deviation and mean changes in (A) basal area (m^2/ha) (B) stem density of shrubs (stems/ha), and (C) stem density of seedlings (stems/ha).

Shrub stem density – Under current sampling effort (mean Satterthwaite df = 4), statistical power was estimated $\geq$90% for changes in stem density of ~2,000 stems/ha or greater. However, the ability to detect smaller changes with 90% power will probably require a doubling of sampling effort. Only 6 of 74 estimates of stem density were >1,000 stems/ha (Table 6), which indicates that current sampling effort has low power to detect even 50% changes in stem density. Figure 4 presents the estimates of power for increasing sample sizes and changes in shrub stem density.

Seedling stem density – Only large changes (>70,000 stems/ha) in seedling stem density are likely detectable under the current sampling effort. Few species have seedling stem densities that exceed 10,000 stems/ha, and most are <3,000 stems/ha (Table 8). Tripling the current sampling effort is still unlikely to provide sufficient power to detect large changes in stem densities for most species. Figure 5 presents the estimates of power for increasing sample sizes and changes in seedling stem density.

Tree-of-heaven – Increases in stem density for tree-of-heaven >1m tall (shrub) ranged from 0 - 143 stems/ha (Table 9). The ability to detect such changes is poor (power < 70%) even if sample sizes were tripled. Average stem density was low for tree-of-heaven in the shrub class (0 - 165 stems/ha; Table 10) such that the power to detect even 100% increases would be quite poor even with substantial increases in sample size (Figure 4).

Changes in stem density for seedlings was highly variable and ranged from -3,368.2 to 206.7 stems/ha (Table 9). Stem density ranged from 0 to 5,288.0 stems/ha (Table 10). Regardless, these densities and changes would have poor chance of being detected under current sampling efforts. Sample sizes would have to be ~4 times greater to detect a change of 5,000 stems/ha, which represents a >100% increase from some of the greatest stem densities that presently exist on SNP.

Flowering Dogwood – Shrub stem densities for flowering dogwood ranged from 15.7 to 329.5 stems/ha (Tables 5 and 6). Under current sampling efforts, power is >80% for changes >1,000 stems/ha. Consequently, the sampling effort would have to increase 2-3 times current levels to detect ~100% changes in current densities. Seedling stem densities were variable, but declined as much as 3,800 stems/ha between sampling periods (Table 7). Regardless, power to detect even large changes in seedling stem density will be nearly impossible without an order of magnitude increase above present sample sizes.

Gypsy moth – The effects of gypsy moth on oak abundance, as measured by changes in basal area for all oak species, has a good chance of being detected under current sample sizes. For example, between sampling periods, oak basal area declined from 29.2 to 26.0 m^2/ha in chestnut oak cover type, and declined from 23.9 to 17.5 m^2/ha in northern red oak cover type. These changes represented a mean change (using paired plots) of -3.2 and -6.4 m^2/ha, respectively. According to Figure 3, the statistical power to detect this magnitude decline is >70% and >90%, respectively. Mean stem densities of oak saplings ranged from 0 to 871 stems/ha, and thus the ability to detect only large changes in stem densities (>1,000 stems/ha) for saplings will likely have acceptable power (Figure 4).

Shrub cover at Big Meadow – The present sampling design should have a reasonably good chance to detect changes in overall shrub coverage, assuming the decline is constant over time. For example, for CV = 13% and a sampling period of five years, statistical power is estimated to be 93% (Figure 6).

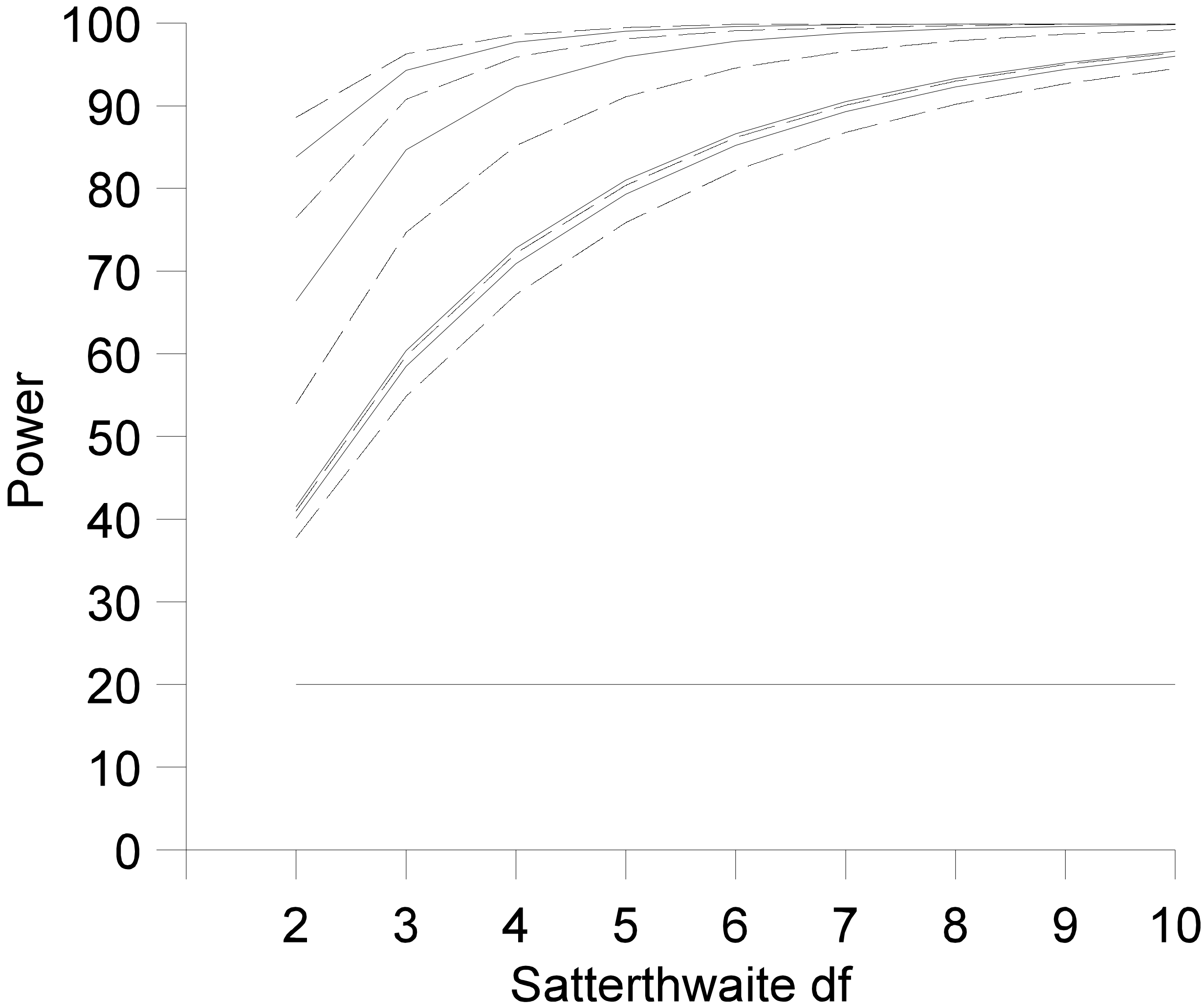


Figure 3. Estimated power to detect a change in tree basal area (m^2/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in basal area of 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 m^2/ha.

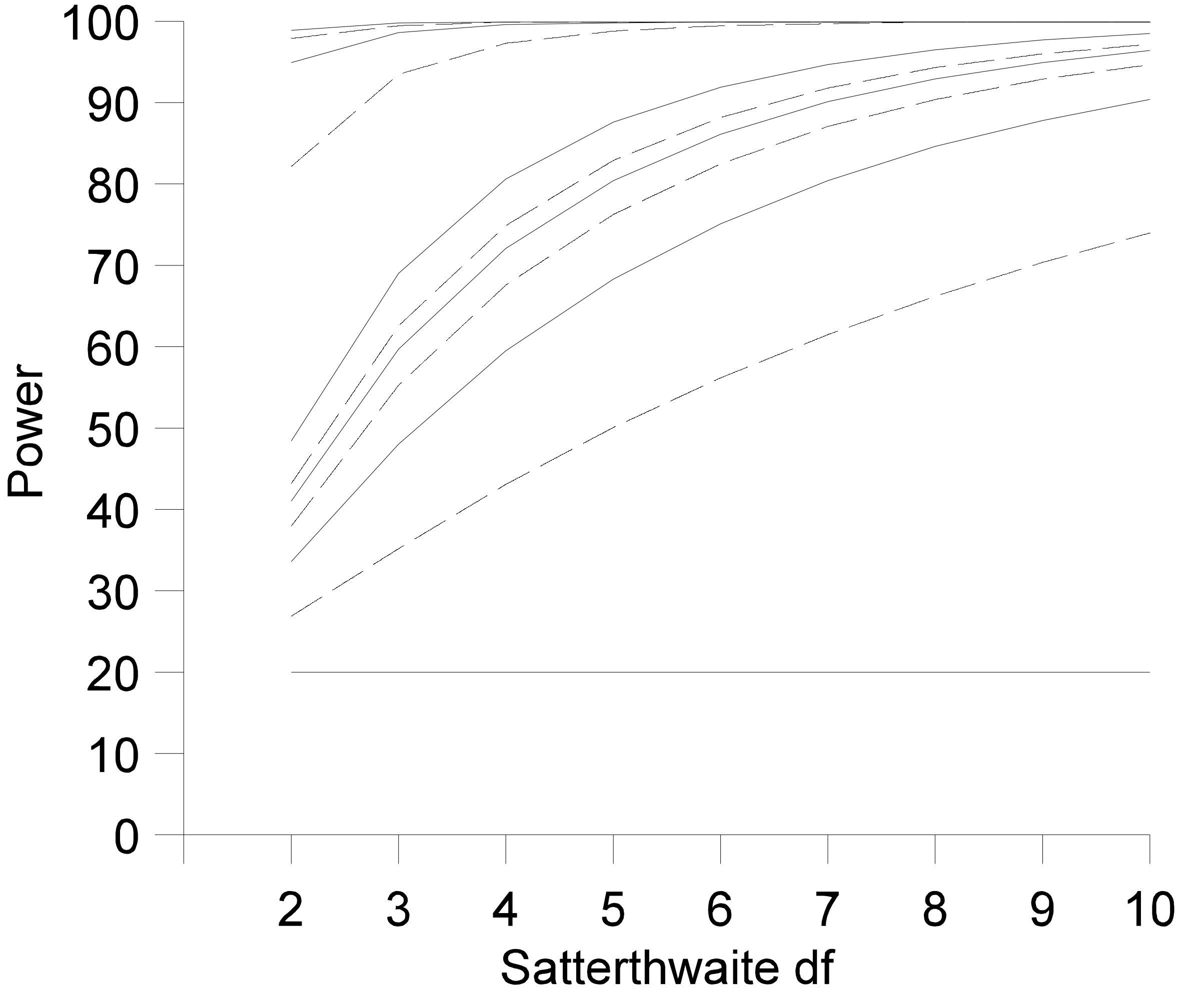


Figure 4. Estimated power to detect a change in shrub stem density (stems/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in stem density of 0, 100, 200, 300, 400, 500, 1,000, 2,000, 3,000, 4,000, and 5,000 stems/ha.

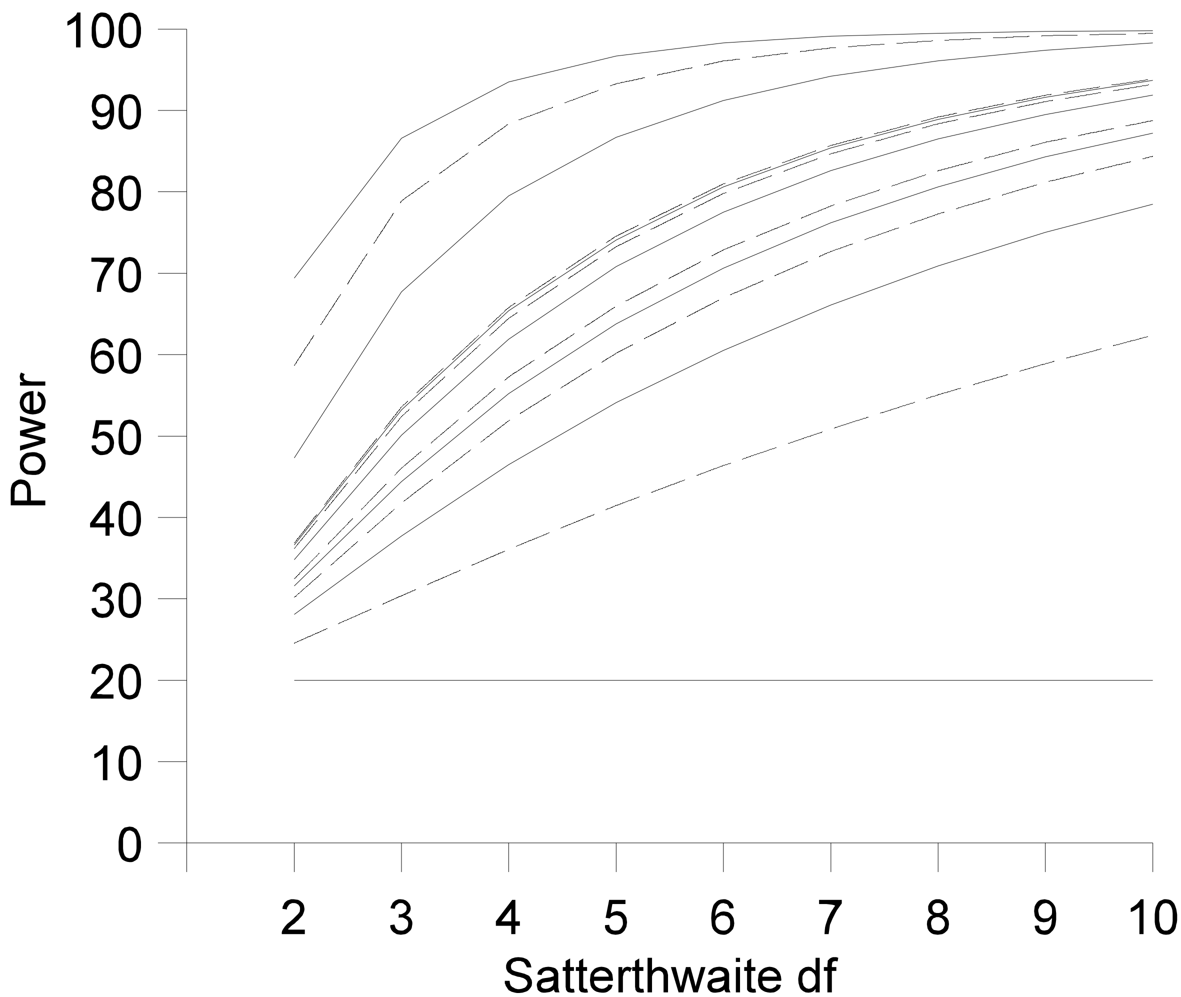


Figure 5. Estimated power to detect a change in seedling stem density (stems/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in stem density of 0, 1,000, 2,000, 3,000, 4,000, 5,000, 10,000, 20,000, 30,000, 40,000, 50,000, 60,000, and 70,000 stems/ha.

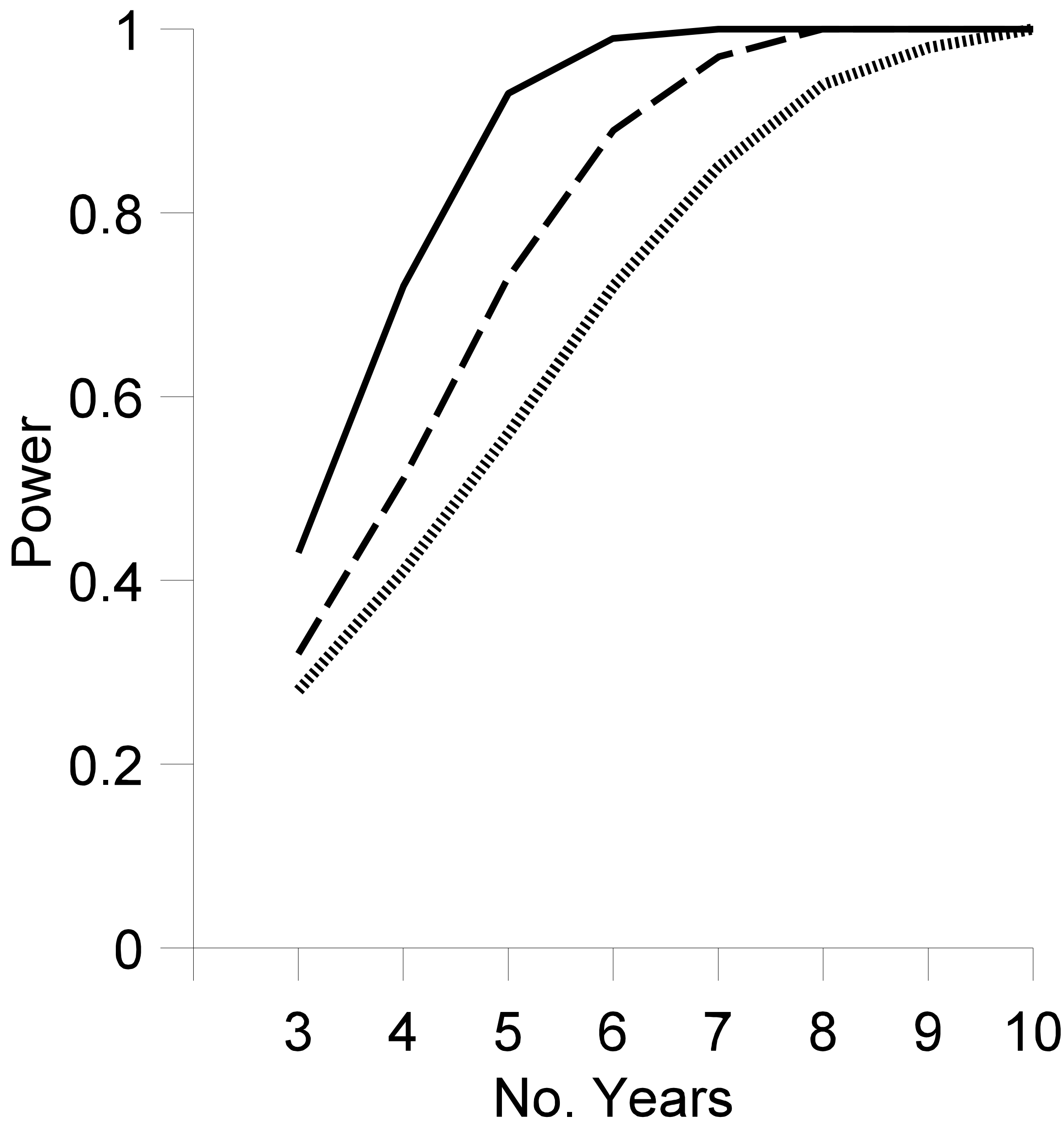


Figure 6. Estimated power to detect a 9.8% decline per year in percent shrub coverage in Big Meadow, Shenandoah National Park for CV = 13% (solid line), 20% (dashed line), and 25% (dotted line) over 3 - 10 years (α = 0.15, 1-tailed *t*-test, exponential decline in shrub coverage).

DISCUSSION AND RECOMMENDATIONS

My recommendations to improve the sampling design of the LTEMS at SNP arise from investigation of the current sampling design, issues related to data collection, and results of the power analysis. Several issues related to current sampling design and data collection are compromising the ability of the LTEMS at SNP to detect or monitor changes in vegetation composition and characteristics. Also, the power analyses indicated that precision of estimates of stem density are not sufficient to detect biologically important changes, although precision seems adequate for monitoring basal area for most tree species and shrub coverage in Big Meadow.

Sampling Design

The stratified sampling design is a good approach to increasing precision of estimates, and the strata of moisture, elevation, and forest cover types seem to be appropriate to identify areas with similar vegetative characteristics (but see Conclusions section). However, there are three problems with the current selection and visitation of sample plots. First, the sample selection is technically flawed because not all areas of the park had a probability of selection >0. This is because the elevation and moisture strata were defined as disjunct intervals with the intention of ensuring that plots from different strata were not physically near one another. Although technically incorrect, I don't believe this is a serious flaw in the sampling scheme.

If additional plots are added to the LTEMS, these disjunct intervals should be eliminated. One means of ensuring an even spatial distribution of plots might be to subdivide strata into equal-sized areas and then randomly select plots from within these substrata with equal probability. These plots among substrata could then be combined into a single strata as if they were never sub-stratified.

Second, some strata contain only a single sample plot. This is such a problem within the hemlock sites that stratified random sample estimators cannot be used if estimates of variance are to be obtained. Other estimators have been proposed in which there is only one unit per stratum (see Cochran 1977:138-140), but they either require knowledge of covariates that correlate strongly with the variable of interest, or *a priori* knowledge of how pairs of plots in different strata should be combined. I do not recommend this approach because it can lead to variance estimates biased low and I believe it would be difficult to identify appropriate pairs of plots among different strata.

Most strata contain only two plots because there is such a large number of strata (42). Therefore, I strongly recommend increasing sample sizes to ensure >1 plot per stratum and preferably more plots per strata for improved precision. Nearly all forest cover types have Satterthwaite df < 10 and the majority are <5, which results in wide confidence intervals. Under the current sampling design, sample sizes would have to be doubled to detect changes in stem density of shrubs and saplings specified for LTEMS objectives (Mahan 2000).

Third, sampling effort is not consistent among forest cover types because of limited personnel resources. Over the period 1988-2000, SNP personnel attempted to visit all plots within a forest cover type during a given field season; for example, all plots in the chestnut oak cover type were surveyed one year, and all plots in cove hardwoods were surveyed the following year. This type of data collection protocol permits estimates of changes in vegetation between two time periods, but it does not permit an estimate of a given parameter (e.g., basal area of northern red oak) for a given year across all forest cover types. Consequently, estimates of changes over time of chestnut oak basal area in the chestnut oak cover type are temporally distinct from the changes estimated for chestnut oak basal area in the northern red oak cover type. This problem greatly limits the ability of LTEMS to monitor changes in vegetation.

The problems associated with sample size and the order in which plots are visited are the two most serious problems with the LTEMS at SNP. Sample sizes are limiting the ability of the LTEMS program to provide precise estimates of vegetation parameters (i.e., CV < 25%). The timing of when sample plots are visited is compromising the ability of the program to detect changes over time because differences among forest cover types are confounded by year of sampling.

I strongly recommend that SNP investigate an alternative sampling design in which some plots are visited annually (or within some multi-year period) and other plots are visited on a systematic basis. This type of sampling design is described in Urquhart et al. (1998) along with the benefits for obtaining point estimates as well as trends over time.

Data Collection

Correct species identification is known to be a problem for similar species (e.g., scarlet oak and red oak; W. Cass, personal communication). These types of errors create difficulties in assessing whether the changes detected in basal area or stem density were caused by recording errors, environmental perturbations, or simply reflect differences in life-history characteristics. For example, scarlet oaks have shorter life spans than red oaks, and if scarlet oaks are incorrectly identified the data may suggest declines in red oak when in fact it simply represents natural mortality in scarlet oaks. The other type of data collection error that was encountered was missing data. For example, in one plot in the pine forest cover type only the dbh of pine trees was entered into the database.

The types of errors outlined above are unavoidable, but can be minimized. Misidentification errors can be reduced by hiring skilled technicians. More importantly, however, the present effort to permanently mark trees with unique identifiers within each permanent plot (W. Cass, personal communication) will greatly reduce misidentification errors. Finally, fully implementing a field-based data-entry system (*sensu* Krueger and Rich 2001) can greatly reduce errors by prompting technicians to document the status of trees measured in previous years, checking for data-entry errors, and eliminating transcription errors from paper datasheets.

Power Analysis

The estimates of power presented in this report are based on estimates of variances obtained in Part I, changes in basal area and stem density deemed reasonable (i.e., expected to occur), and assumptions about the distribution of those changes. Specifically, I assumed the estimated change followed a *t* distribution and that variance was positively correlated with the mean. Consequently, the estimates of power presented in this report contain some unknown bias and precision; however, bias is likely low although precision may be poor (Gerard et al. 1998:805).

Power analyses cannot be used to interpret results, and thus applying power curves generated in Part II of this report to assess specific results presented in Part I is not recommended to determine the "statistical power" of an estimate of change (see Gerard et al. 1998). Once data have been collected and estimates calculated, confidence intervals should be used to assess whether changes have occurred (e.g., whether the CI encompasses zero) and CVs, or the lengths of confidence intervals, should be used to assess the precision of estimates.

The value of the power analysis presented in this report is to provide guidance on the ability of the current sampling design to detect specified changes in basal area or stem density. Moreover, alternative study designs can be evaluated with respect to specific objectives and to some extent the benefit of design changes (primarily increased sample size) can be estimated.

In my opinion, the number of sample plots need to be increased for two reasons: (1) some strata do not contain >1 sample plot, and (2) power curves suggest that only relatively large changes in shrub stem density have a reasonable chance of being detected. Changes in basal area of >5 m^2/ha have >90% chance of being detected under the current sampling design at SNP. However, only changes >2,000 stems/ha have a >90% chance of being detected for shrubs (i.e., vegetation >1 m tall). Most stem densities of shrubs are <1,000 such that sample sizes should permit changes of 400 - 500 stems/ha be detectable with power >80%.

I do not believe it is reasonable to expect to be able to detect even large changes in seedling stem density (i.e., vegetation <1 m tall). The power curves suggest that doubling current sample sizes would still only provide sufficient power to detect changes of >20,000 stems/ha. It is likely that the inherent spatial variability in abundance of seedlings will make meeting any reasonable objective costly and logistically impossible.

The power analysis to detect a trend in shrub coverage is likely a conservative estimate, however, and may not be the best measure of detecting changes. Because shrub coverage is being controlled in Big Meadow via mowing and/or burning, it is reasonable to believe that shrub coverage has in fact declined (similar to the situation in which logging reduces basal area), and a more important question is whether estimated changes in shrub coverage will have adequate precision to detect biologically important changes. Given that the estimates of paired differences and absolute amounts of shrub coverage pre- and post-treatment had CVs < 20%, I believe biologically important changes in shrub coverage will be detectable under the current sampling design. However, obtaining precise estimates of changes in shrub coverage for individual species probably will be possible only for the most abundant species.

CONCLUSIONS

The most important change I would recommend for the LTEMS program at SNP would be to implement a sampling design that will permit regular estimates of park-wide parameters (e.g., an estimate of basal area), yet also permit estimates of trends over time (*sensu* Urquhart et al. 1998). I believe that this type of sampling design would greatly improve the inferences that can be obtained from LTEMS regarding changes in the vegetative communities in the park.

However, before such a design is implemented, there are spatial issues regarding monitoring changes in the vegetation in SNP which must be considered. Traditional sampling theory (e.g., Cochran 1977) does not explicitly consider spatial configuration of sampled units in the sampling design. For example, stratified sampling is based on an assumption that the strata do not change, which may not be a good assumption for vegetation types that may be changing over time (e.g., pine vegetation types being replaced by hardwoods). I recommend that how the spatial distribution of vegetation types will be monitored be considered before any changes to the the monitoring program become implemented.

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